
Non-SUSY searches at the Tevatron

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For the CDF and D₀ Collaborations





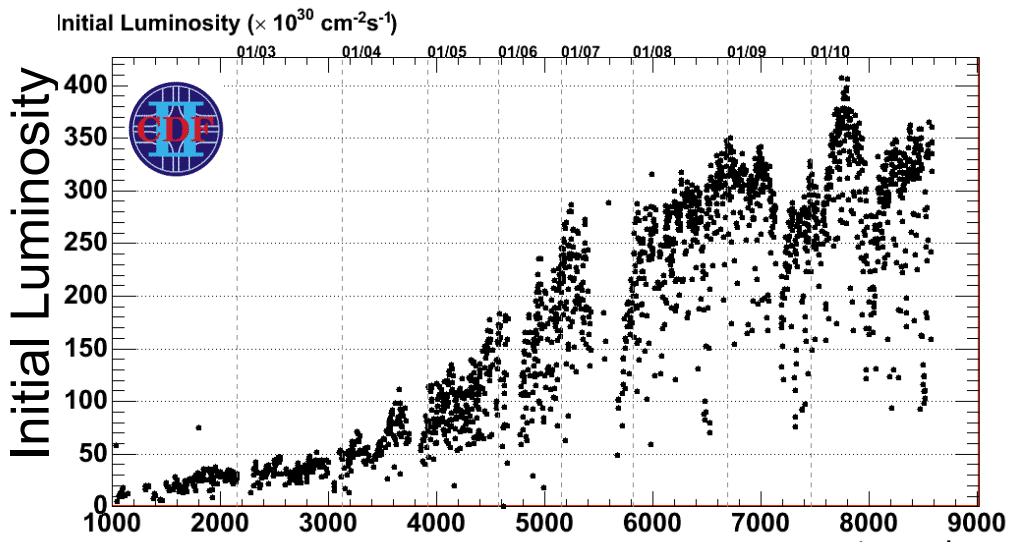
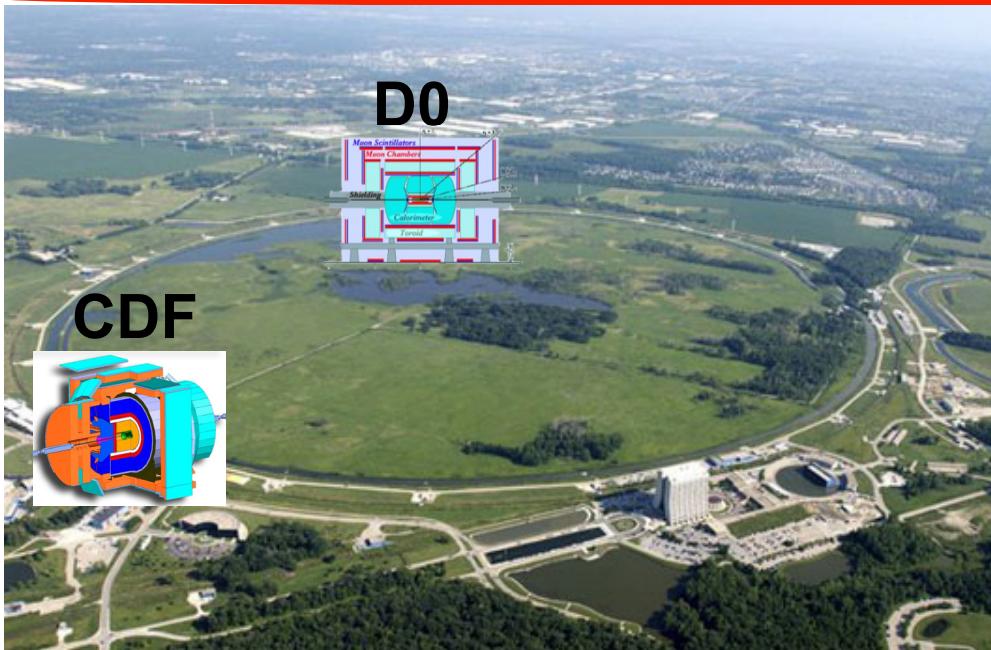
- Although extremely successful, the Standard Model does not answer all our basic questions about nature
 - Why are the Planck scale and the electroweak scale 17 orders of magnitude apart (and how can we avoid the “fine-tuning”)
 - How is gravity incorporated?
 - What is the origin of mass?
 - What is the source of dark matter and dark energy?
 - Why is there a boson/fermion asymmetry?
 - Why is there a particle/antiparticle asymmetry?
 - Why do we have several interactions instead of one unified one?
 -
- Our job as experimentalists is
 - to perform experiments to discover new-physics effects that could give answers to the above questions
 - to perform experiments to test current theories that offer answers to the above questions



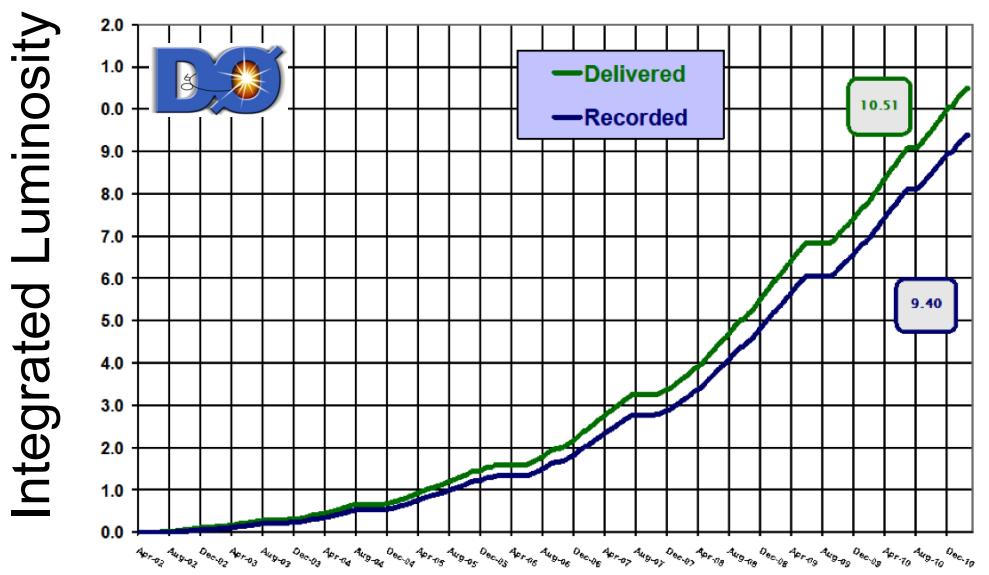
UNM



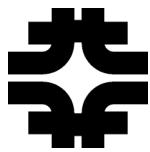
The Tevatron



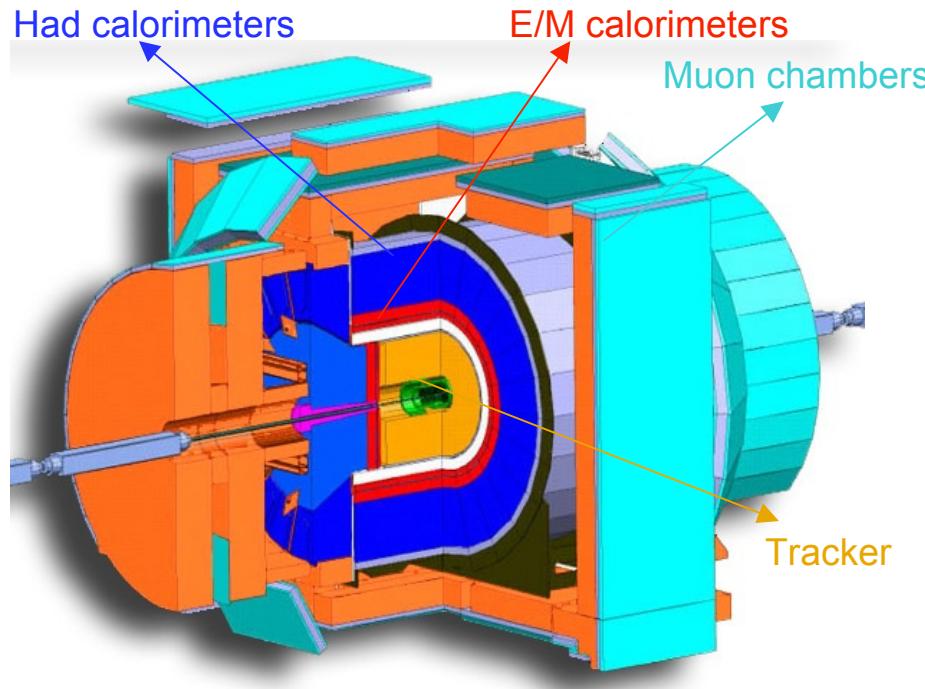
- Tevatron collides protons with antiprotons at 1.96 TeV center-of-mass energy
- Instantaneous luminosity $350\text{-}400 \times 10^{30} \text{ cm}^{-2}$
- Delivered luminosity $\sim 11 \text{ fb}^{-1}$
- Recorded luminosity: $\sim 9 \text{ fb}^{-1}$ per experiment
- **Presented in this talk up to 6 fb^{-1}**



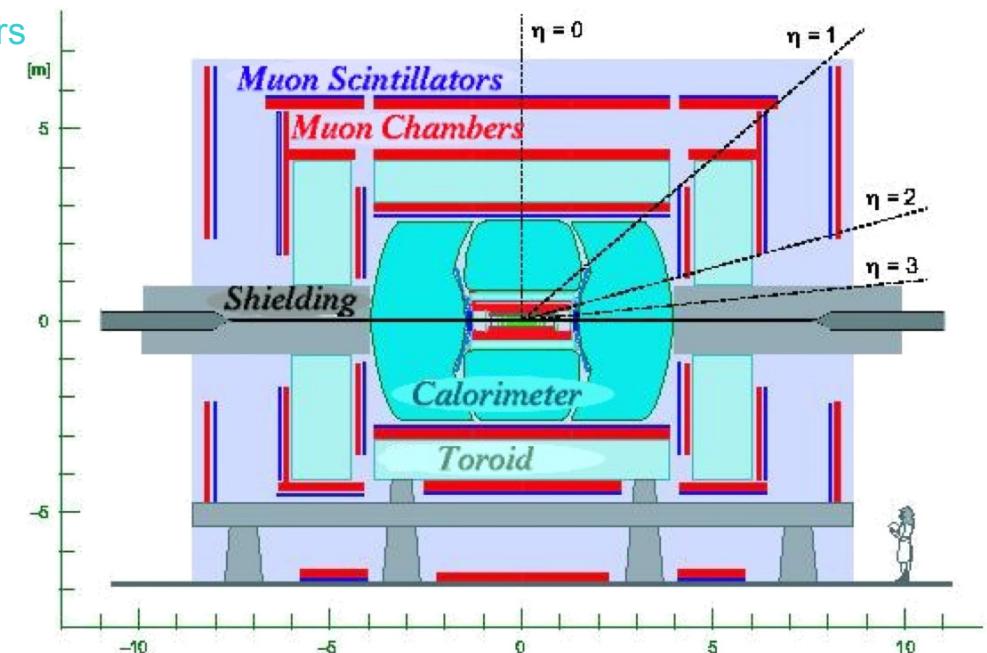
The CDF and D0 detectors



CDF

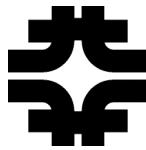


D0



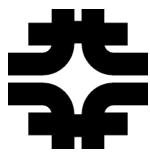
- Central silicon and drift tracking
- Lead/Steel+scintillator calorimeter
- Outer muon chambers
- Magnetic field of 1.4 Tesla

- Central silicon and drift tracking
- Uranium/Steel+Liquid-argon calorimeter
- Outer muon chambers
- Magnetic field of 1.8 Tesla

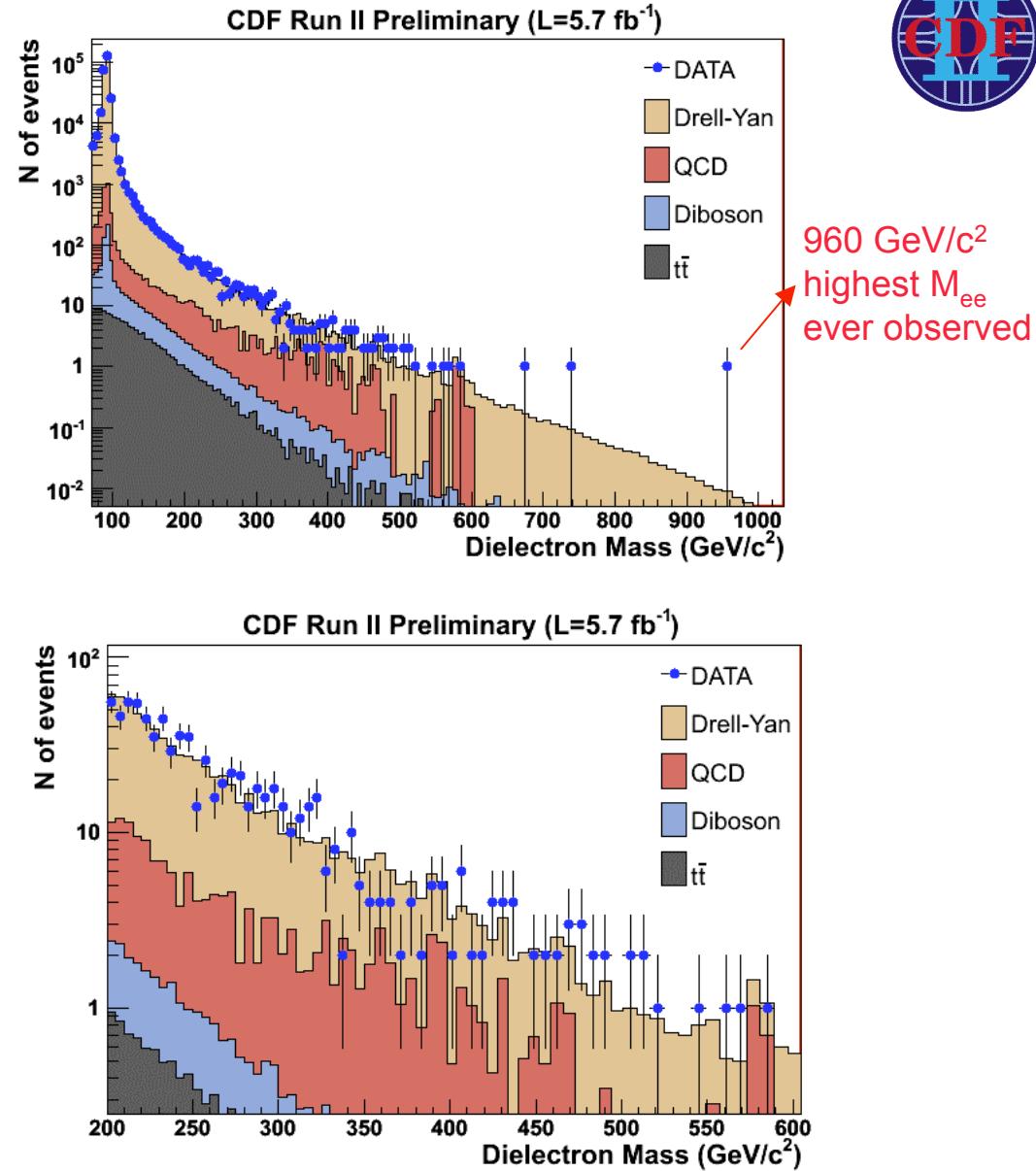


- Searches for phenomena predicted by specific current theories
 - SUSY ← Covered by the previous talks
 - RS-gravitons
 - 4th generation
 - New gauge bosons
 - Universal Extra dimensions
 - Technicolor
 - Vectorlike quarks
- Searches for signatures inconsistent with the Standard Model
 - Mass resonances
 - Rare events
 - Not necessarily predicted by current theories
- Even searches that look for particles predicted by current theories can be generic enough to discover the unpredictable

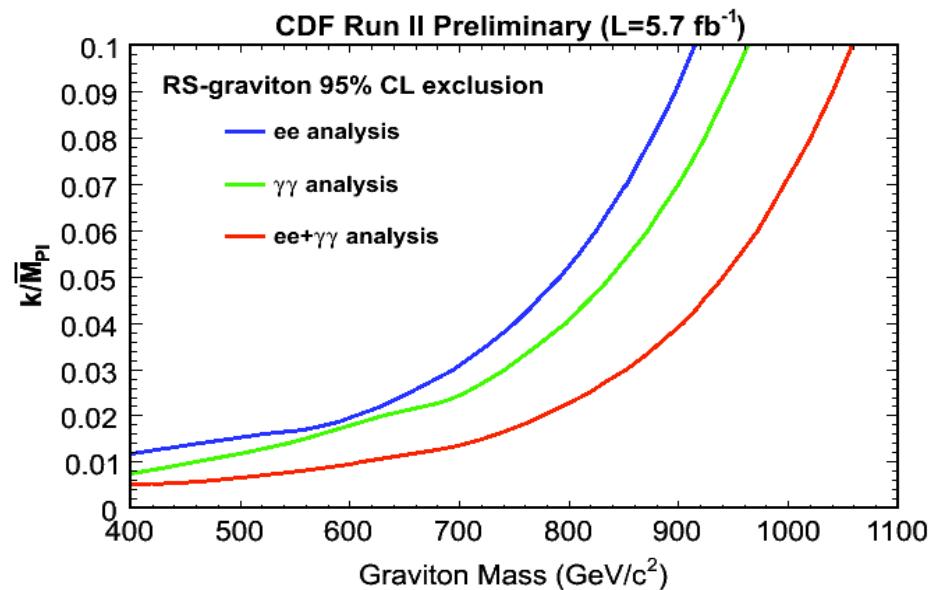
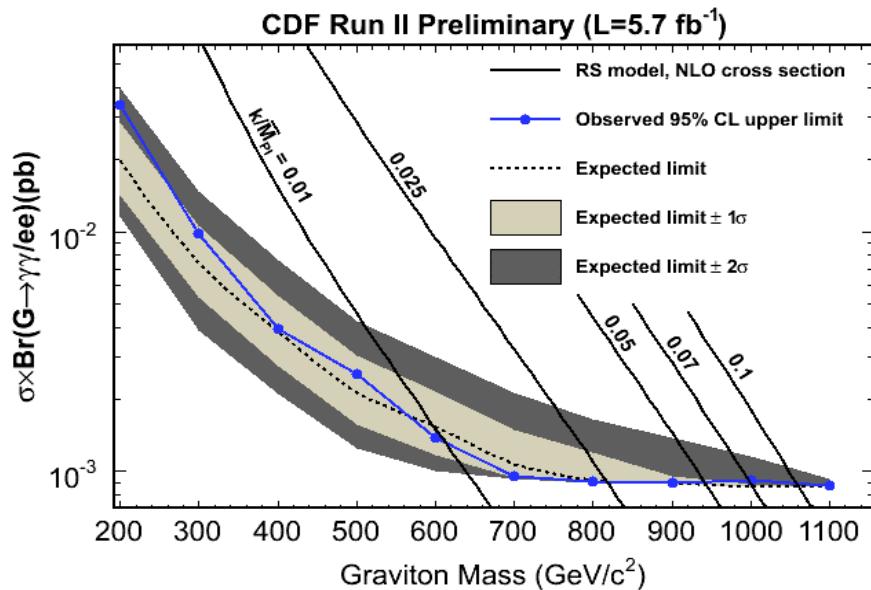
Search for new dielectron resonances and RS gravitons



- $L = 5.7 \text{ fb}^{-1}$
- Selection:
 - 2 electrons (one central > 20 GeV)
 - Isolation and impact parameter applied
 - No opposite charge requirement
- Main backgrounds:
 - Drell-Yan to dielectrons
 - QCD: electron+jet(fake)
 - Minor diboson, top
- Results:
 - Excellent agreement in dielectron mass spectrum
 - Observed the highest mass dielectron ever detected
(probability to see ≥ 1 event with mass $\geq 960 \text{ GeV}/c^2$ is 4%)



Search for new dielectron resonances and RS gravitons (2)



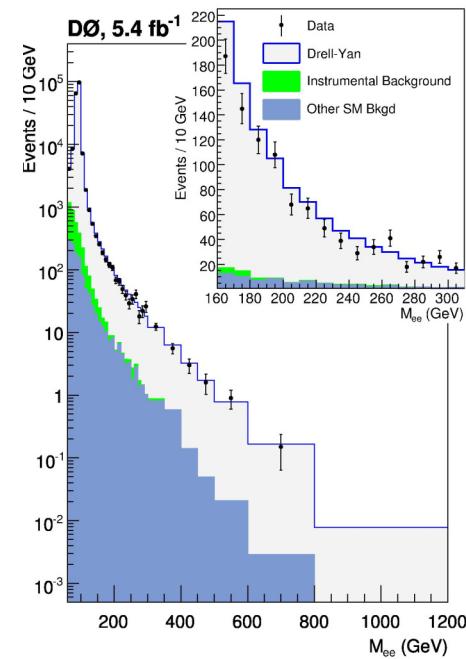
- Combined with the $\gamma\gamma$ analysis, the combined RS graviton 95% CL limit is **1058 GeV/c^2** (for a mass-depended RS K-factor) or **1092 GeV/c^2** (for a fixed K-factor at 1.54)

CDF public note 10405

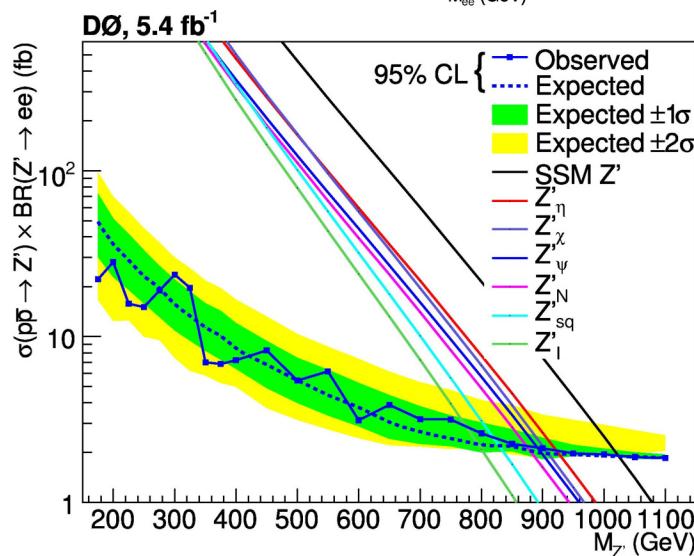
$\gamma\gamma$ result: Phys. Rev. D **83**, 011102 (2011)

- $L = 5.4 \text{ fb}^{-1}$
- Selection:
 - 2 electrons $p_T > 25 \text{ GeV}/c$
 - No opposite charge required
- Main backgrounds:
 - Drell-Yan to dielectrons
 - QCD: electron+jet(fake)
 - Minor diboson, top
 - Backgrounds fitted to data at the Z region
- Results:
 - Good agreement in dielectron mass spectrum
 - $M(Z') > 1023 \text{ GeV}$ at 95% CL (SM couplings)

Phys. Lett. B 695, 88 (2011)



Dielectron mass

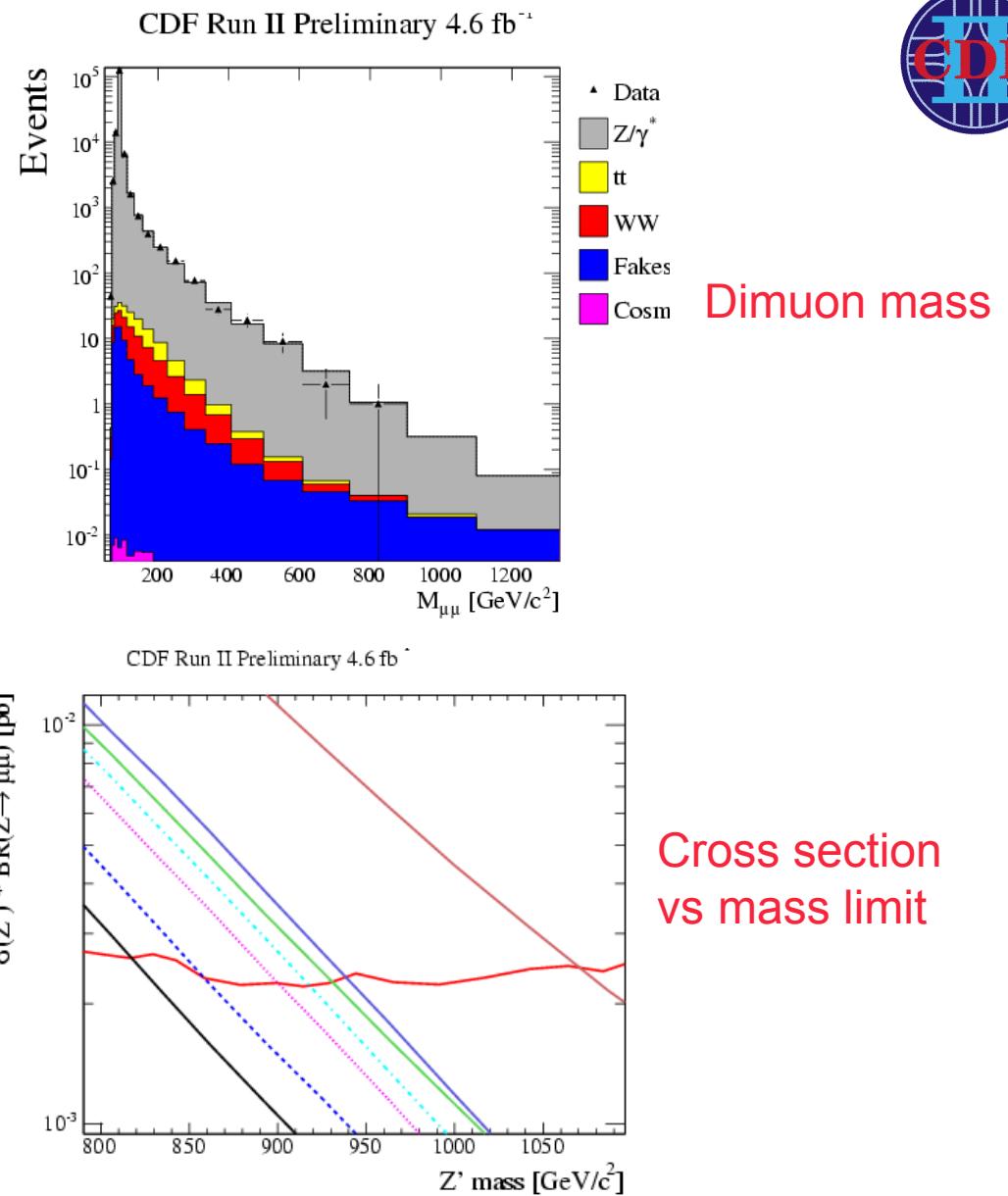


Cross section
vs mass limit

Search for $Z' \rightarrow \mu\mu$

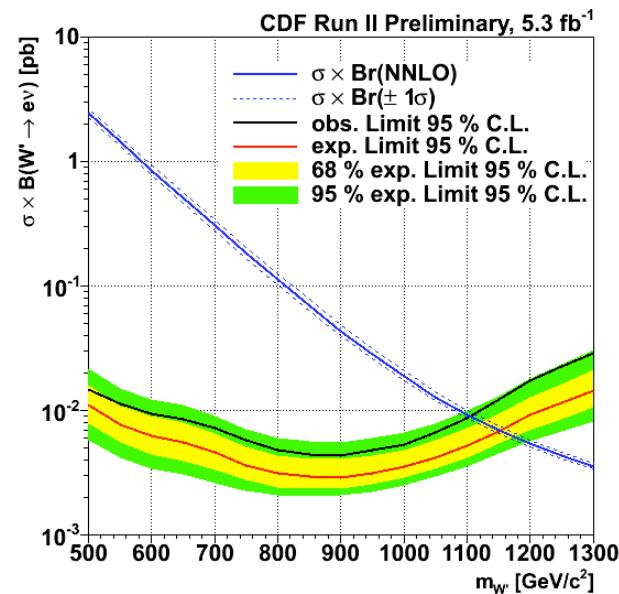
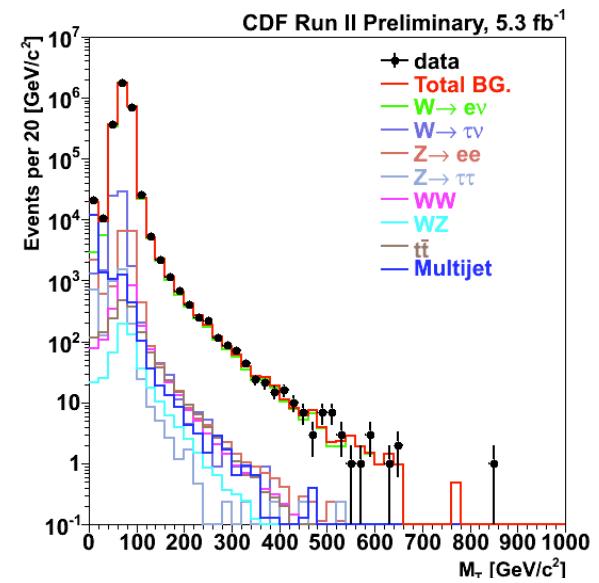
- $L = 4.6 \text{ fb}^{-1}$
- Selection:
 - 2 muons $p_T > 30 \text{ GeV}/c$
 - Opposite charge
 - Cosmic veto
- Main backgrounds:
 - Drell-Yan to dimuons
 - Minor muon+track(fake), cosmic, diboson, top
- Results:
 - Good agreement in dimuon mass spectrum
 - $M(Z') > 1071 \text{ GeV}$ at 95% CL (SM couplings)

arXiv:1101.4578



- $L = 5.3 \text{ fb}^{-1}$
- Selection:
 - 1 electron $E_T > 25 \text{ GeV}$
 - MET $> 25 \text{ GeV}$
 - $0.4 < E_T/\text{MET} < 2.5$
 - Dielectron veto
- Main backgrounds:
 - $W \rightarrow e\nu$
 - W/Z decays to taus
 - QCD multijet
- Results:
 - Good agreement in M_T
 - $M(W') > 1.12 \text{ TeV}$ at 95% CL
(SM couplings, L-R symmetric)

Phys. Rev. D **83**, 031102 (2011)

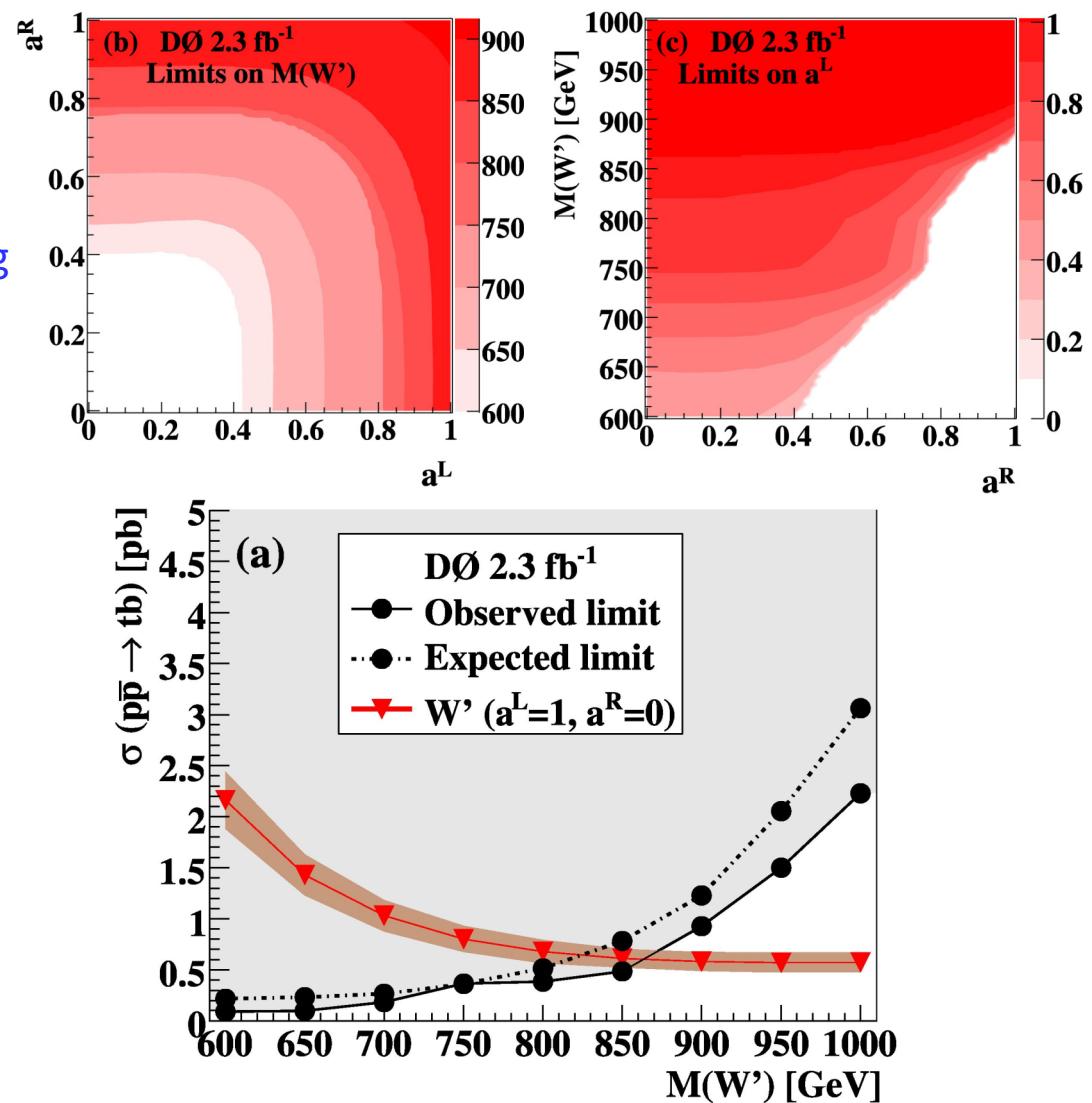


Electron-MET
Transverse
Mass M_T

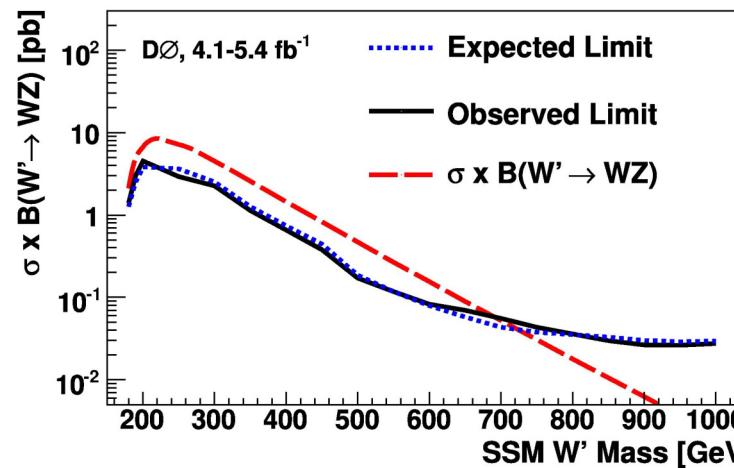
Cross section
vs mass limit

- $L = 2.3 \text{ fb}^{-1}$
- Investigate $W' \rightarrow tb \rightarrow b\bar{b}l\nu$
- Selection:
 - 1 e/ μ , $p_T > 15, 20 \text{ GeV}/c$
 - 2, 3 or 4 jets, $E_T > 15 \text{ GeV}$ (leading $> 25 \text{ GeV}$)
 - 1 or 2 b tags
 - Total invariant mass $> 400 \text{ GeV}/c^2$
- Main backgrounds:
 - $W + \text{jets}$, top
 - Minor: multi-jets, $Z + \text{jets}$
- Results:
 - Limits calculated for all combinations of left-handed and right-handed couplings
 - $M(W') > 863\text{-}916 \text{ GeV}/c^2$

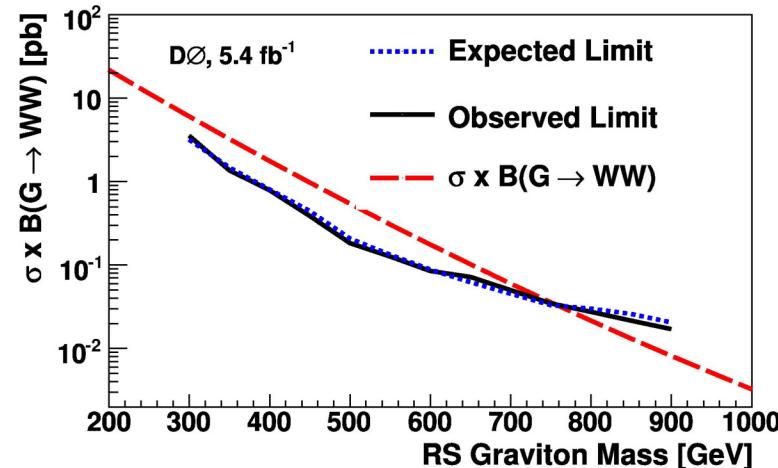
arXiv:1101.0806v2



- $L = 4.1$ (trileptons)
= 5.4 fb^{-1} (jet + 1 or 2 leptons)
- Selection 1 (leptonic W)
 - $1 e/\mu > 20 \text{ GeV}$
 - 1 or 2 jets $> 20 \text{ GeV}$
 - MET $> 20 \text{ GeV}$
- Selection 2 (leptonic Z)
 - 2 ee or 2 $\mu\mu > 20 \text{ GeV}$
 - 1 or 2 jets $> 20 \text{ GeV}$
 - MET $< 50 \text{ GeV}$
 - $70 < M_{\parallel} < 110 \text{ GeV}/c^2$
- Selection 3 (leptonic W and Z)
 - 3 $e/\mu > 20 \text{ GeV}$
 - MET $> 30 \text{ GeV}$
- Boosted jets from W/Z decays could be reconstructed as 2 jets or a 1 jet
 - M_j or M_{jj} cuts
- Main backgrounds:
 - W+jets, Z+jets, diboson

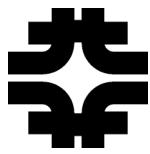


SM couplings

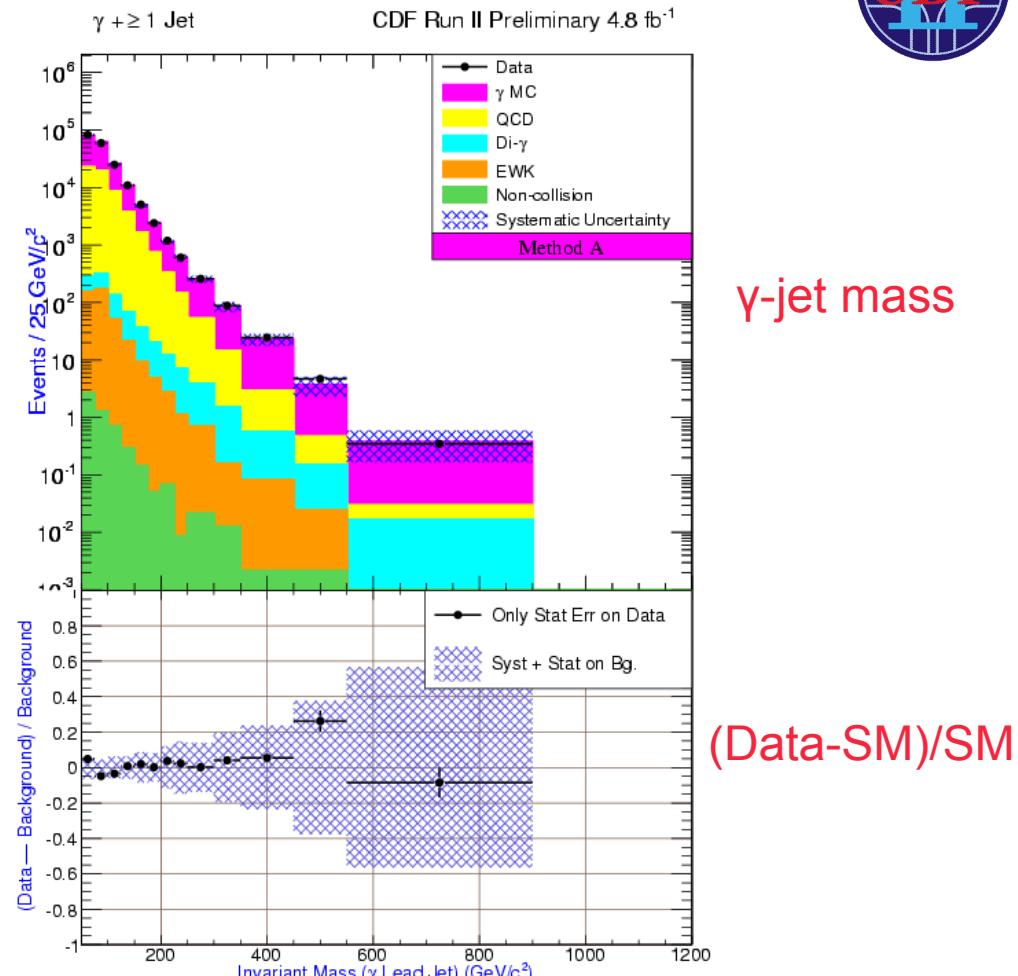
 $k/M_{PL}=0.1$ $M(W') > 690 \text{ GeV}/c^2$ $M(G) > 754 \text{ GeV}/c^2$

arXiv:1011.6278

Search for anomalous $\gamma + \text{jets}$ (+MET)

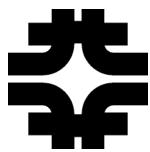


- $L = 4.8 \text{ fb}^{-1}$
- Selection:
 - 1 photon with $E_T > 30 \text{ GeV}$
 - ≥ 1 or ≥ 2 jets with $E_T > 15 \text{ GeV}$
 - $\Delta\Phi(\gamma, \text{jet}) > 0.4$
 - Repeated for MET>20
- Main backgrounds:
 - SM $\gamma, \gamma\gamma, \text{charged-lepton}$
 - QCD multi-jet (fake-photon)
 - Cosmics, beam halo
- Results:
 - Good agreement with SM in several kinematic distributions



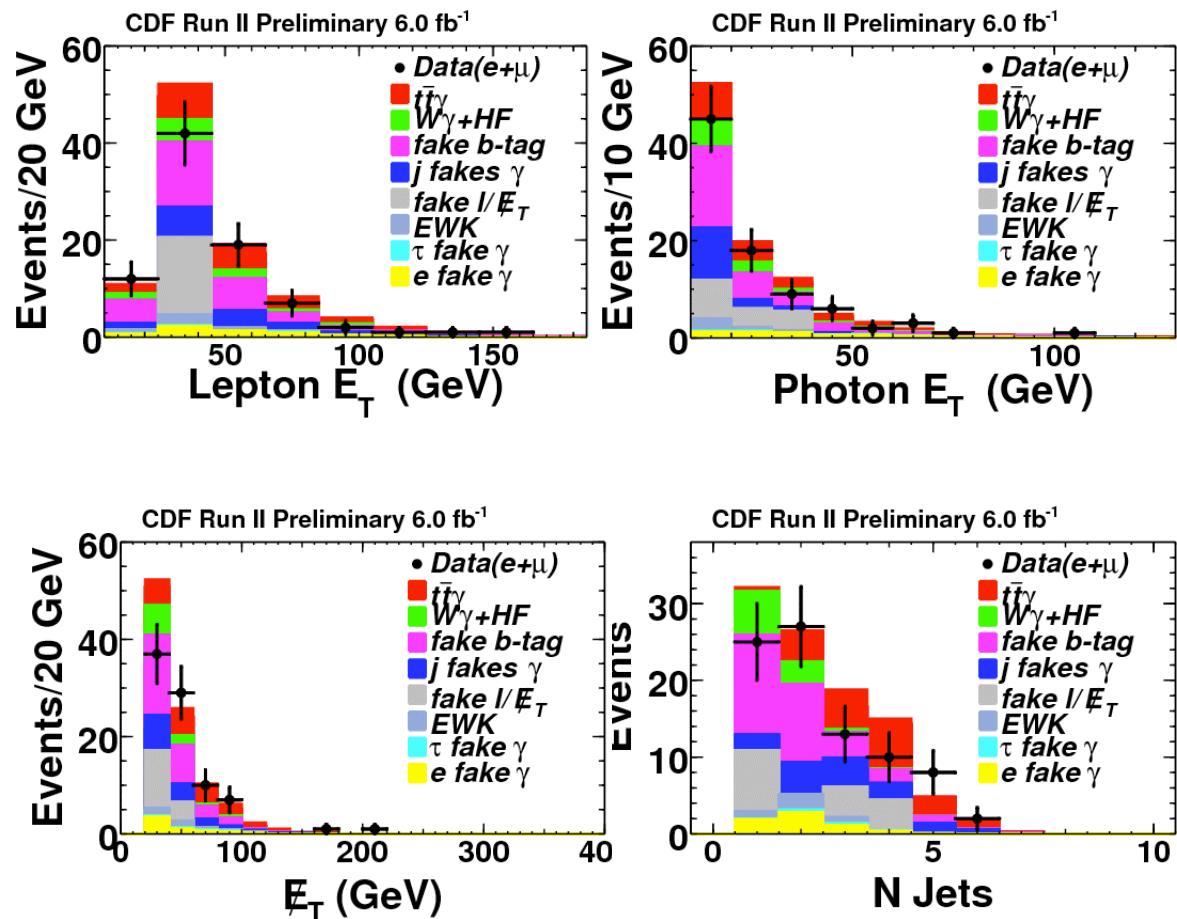
CDF public note 10355

Lepton+gamma+MET+b-quark



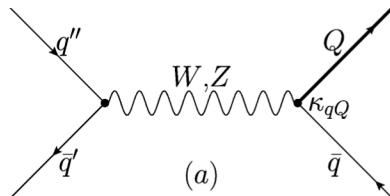
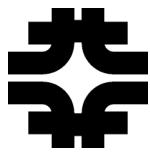
- Signal could be due to t-tbar+photon with semileptonic decay or due to some new physics

- $L = 6.0 \text{ fb}^{-1}$
- Select an electron or muon with $E_T > 20 \text{ GeV}$, $\text{MET} > 20 \text{ GeV}$, photon with $E_T > 12 \text{ GeV}$
- b-tagged jet with $E_T > 20 \text{ GeV}$
- Main background: t-tbar+ γ and $W\gamma+\text{jets}$
- Results consistent with the SM
- Impressive measurement of t-tbar+ γ cross-section:
 $\sigma = 0.18 \pm 0.07 \text{ (stat)} \pm 0.04 \text{ (syst)}$
 $\pm 0.01 \text{ (lum) pb}$

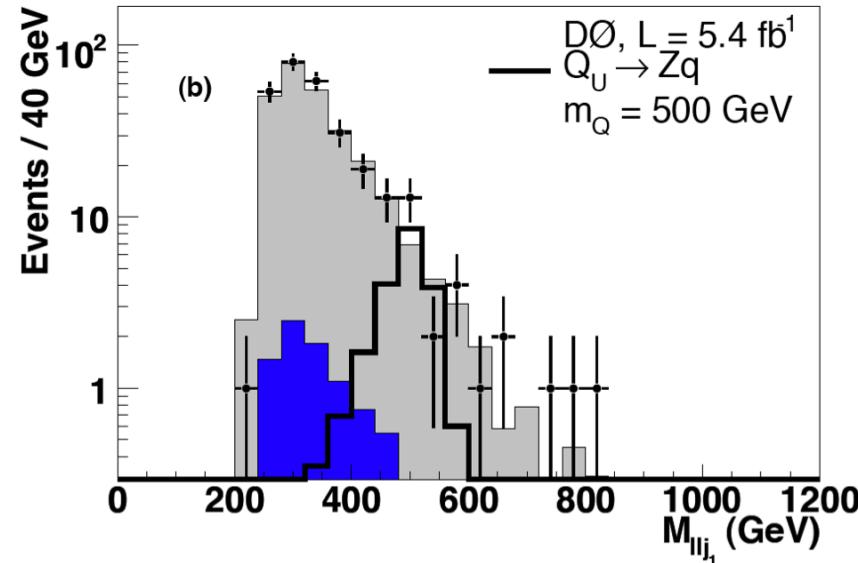


CDF public note 10270

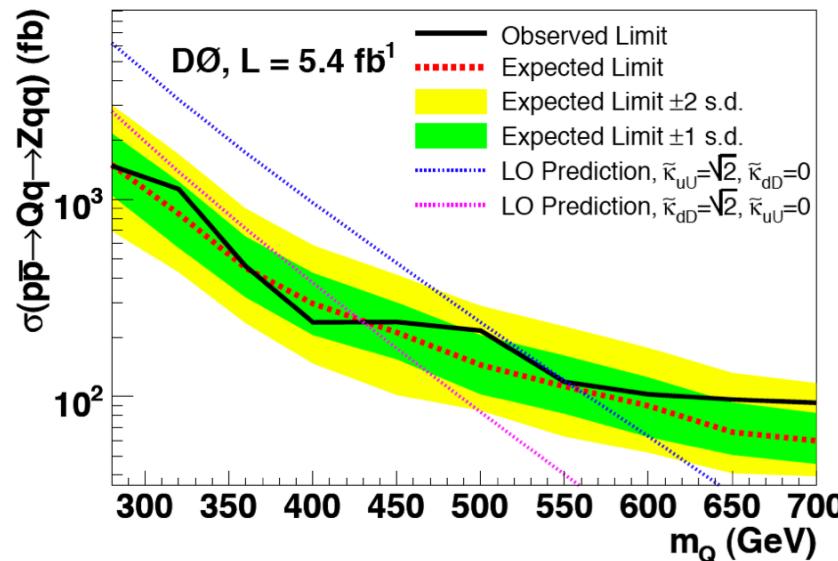
Search for vector-like quarks in Z+jets



- $L = 5.4 \text{ fb}^{-1}$
- Signature: **vector boson+ 2 jet**
- Selection:
 - 2 e or 2 μ > 20 GeV
 - $p_T(\text{dilepton}) > 100 \text{ GeV}/c$
 - $\geq 2 \text{ jets} > 20 \text{ GeV}$
(leading > 100 GeV)
 - MET < 50 GeV
 - $70 < M_{\parallel} < 110 \text{ GeV}/c^2$
- Main backgrounds:
 - Z+jets
- Results:
 - $M(Q) > 430\text{-}551 \text{ GeV}$ at 95% CL
(depending on the couplings)



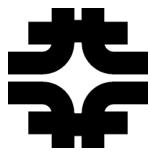
I+I+jet mass



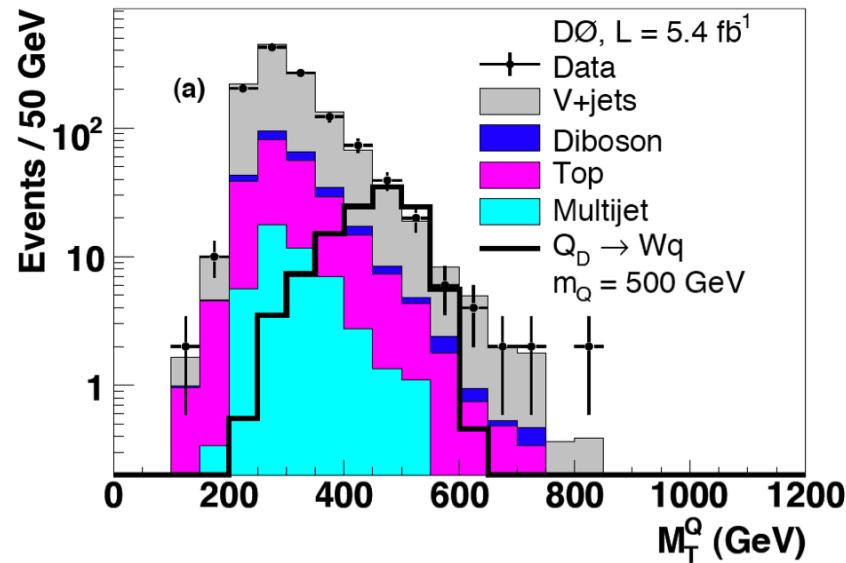
Cross section
vs. mass limit

Phys. Rev. Lett. **106**, 081801 (2011)

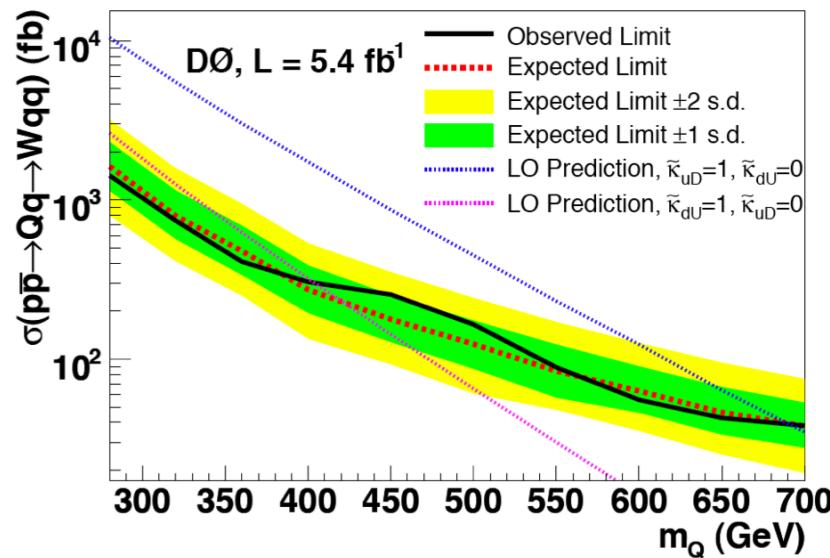
Search for vector-like quarks in W+jets



- $L = 5.4 \text{ fb}^{-1}$
- Selection:
 - $1 e/\mu > 50 \text{ GeV}$
 - $\geq 2 \text{ jets} > 20 \text{ GeV}$
(leading $> 100 \text{ GeV}$)
 - $\text{MET} > 50/40 \text{ GeV}$
 - $2M_T^W + \text{MET} > 80 \text{ GeV}$
- Main backgrounds:
 - W+jets
 - Top quarks
 - QCD multi-jet, Z+jets, diboson
- Results:
 - $M(Q) > 403\text{-}693 \text{ GeV}$ at 95% CL
(depending on the couplings)



Q transverse mass



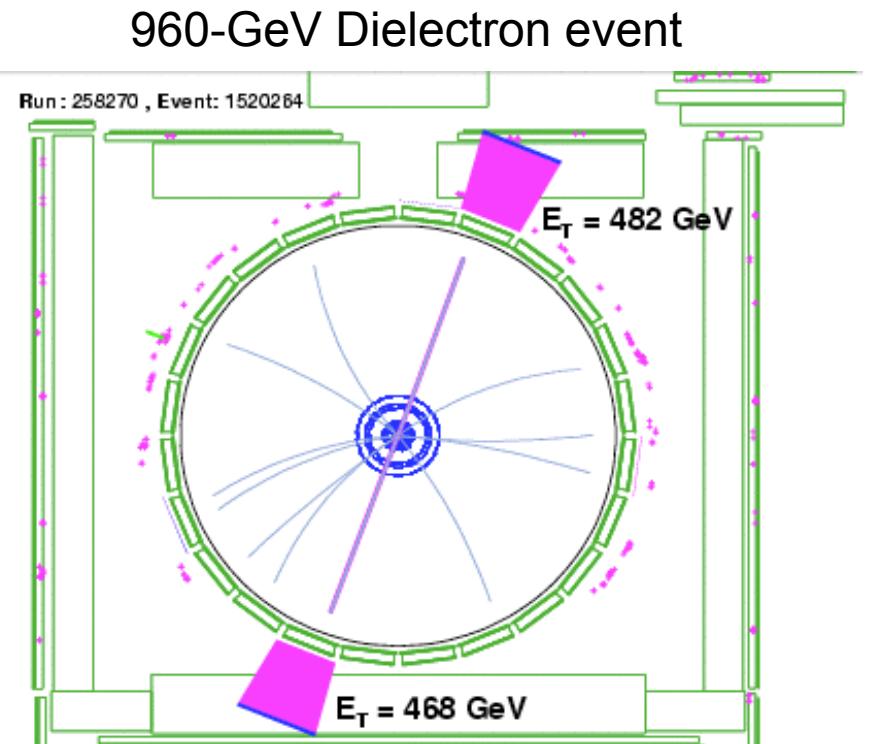
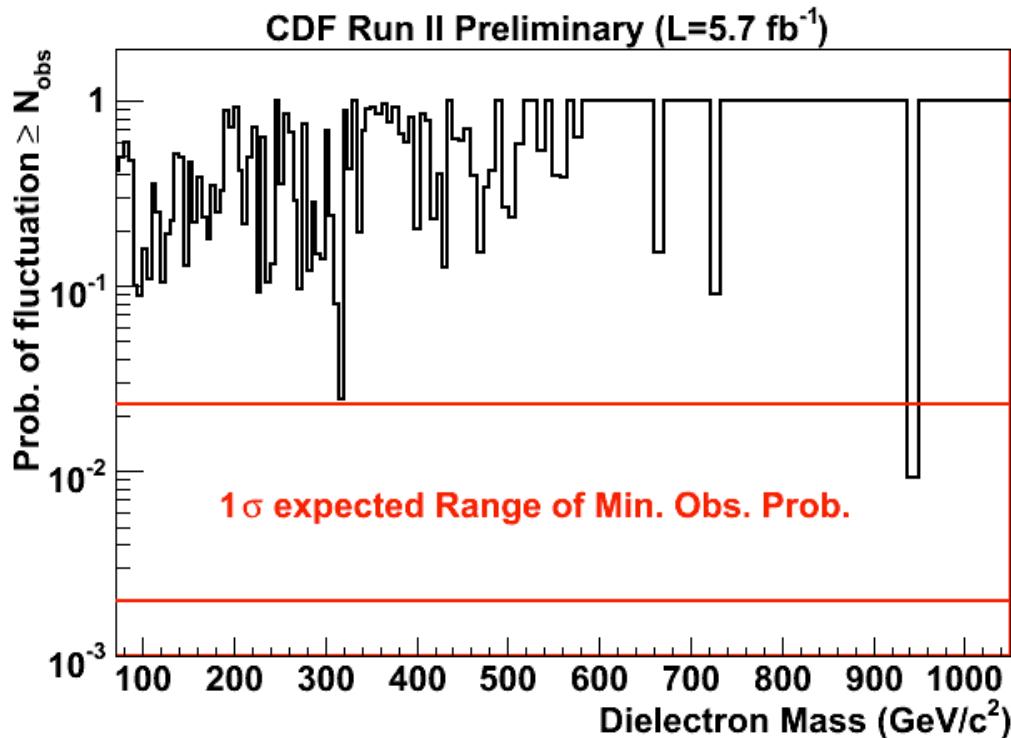
Cross section vs. mass limit

Phys. Rev. Lett. 106, 081801 (2011)

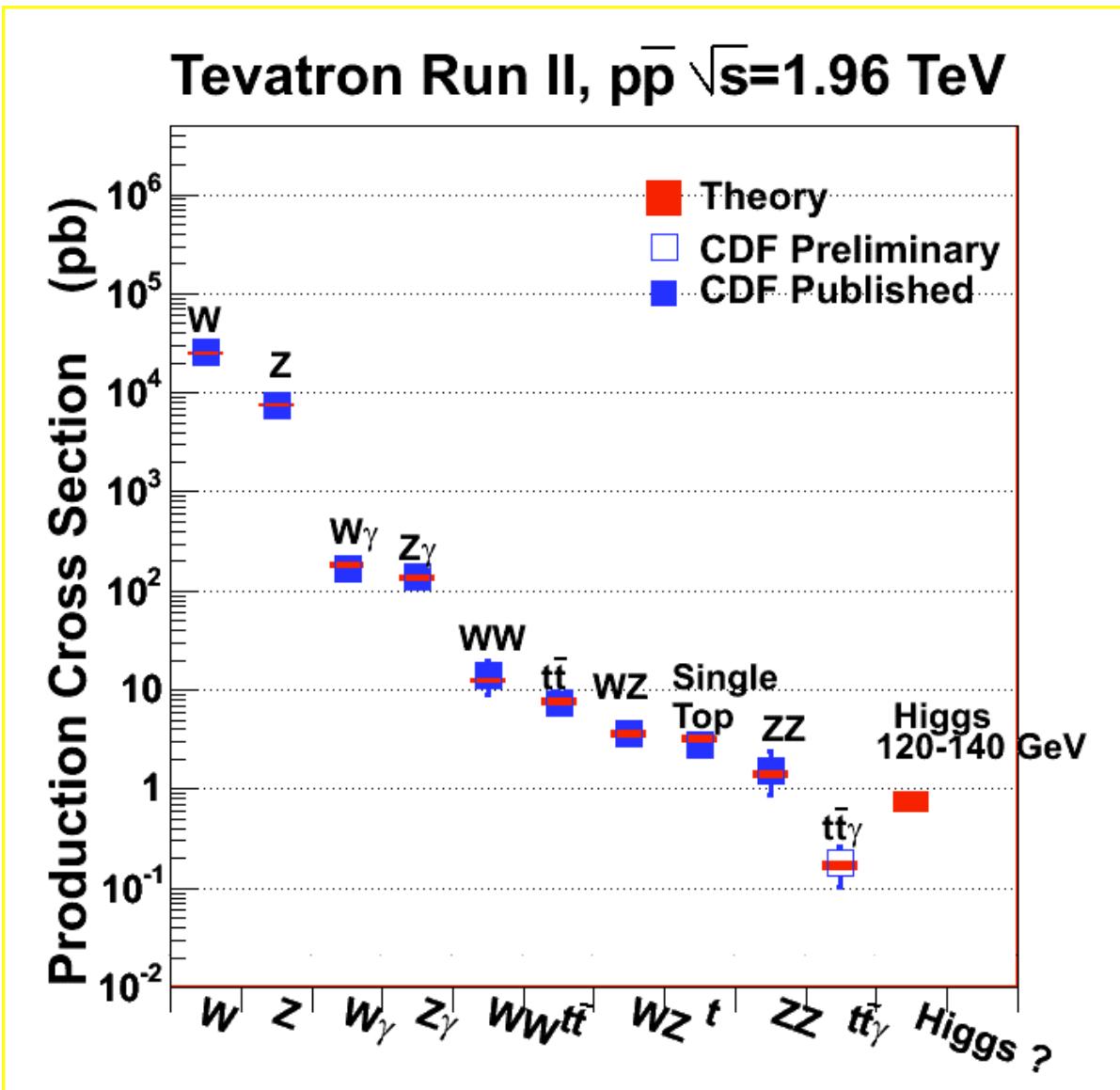
Conclusions

- We are searching for new physics in many different final states
 - In a model-independent or in model-inspired manner
- Our goal is to complete the Tevatron new-physics program by performing as many searches as possible, using all the collected data
- We hope that we either discover something new or give good hints to LHC
- More information and continuous updated can be found in the following new-physics D0 and CDF web pages:
 - **CDF Exotics** : <http://www-cdf.fnal.gov/physics/exotic/exotic.html>
 - **D0 New phenomena** : <http://www-d0.fnal.gov/Run2Physics/WWW/results/np.htm>

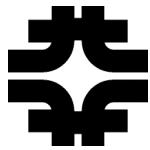
Backup



Top pair + gamma cross section

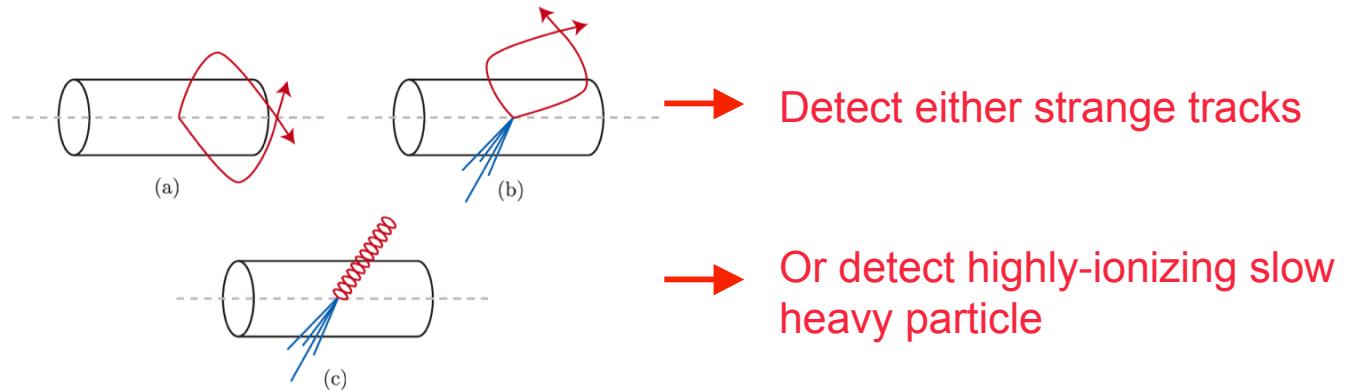


Quarks and Hidden Valleys



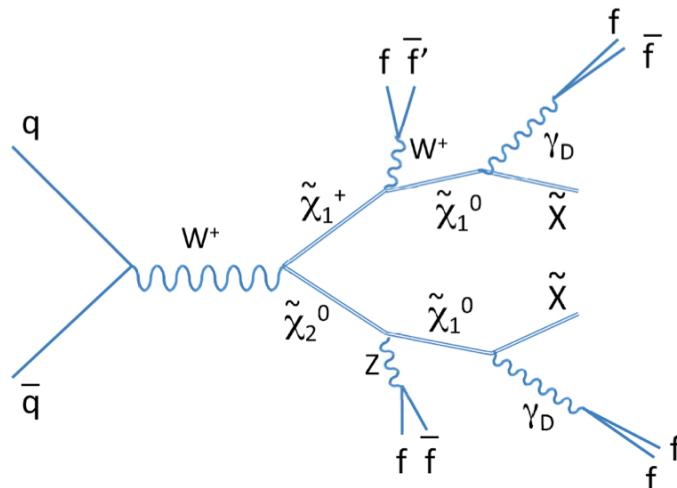
- Extra QCD-like $SU(N)$ theories predict new kind of quarks. Parameters are the scale Λ where “infracolor” becomes strong and the mass M_Q of the “quirks”

Kang and Luty (2008)
arXiv:0805.4642v3 [hep-ph]



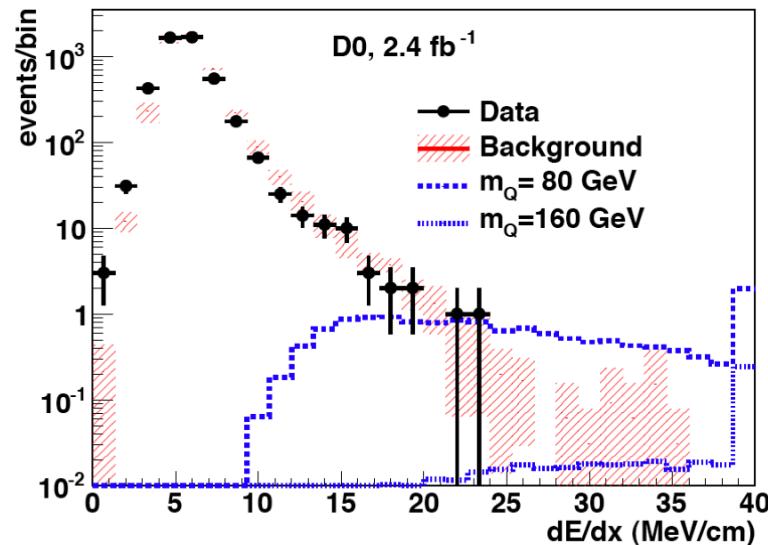
- SUSY hidden sector γ_D could give rise to “lepton jets” that are detectable at the Tevatron

Hanet *et al.*,
J. High Energy Phys. **07**, 008 (2008)
Strassler and Zurek,
Phys. Lett. B **651**, 374 (2007)

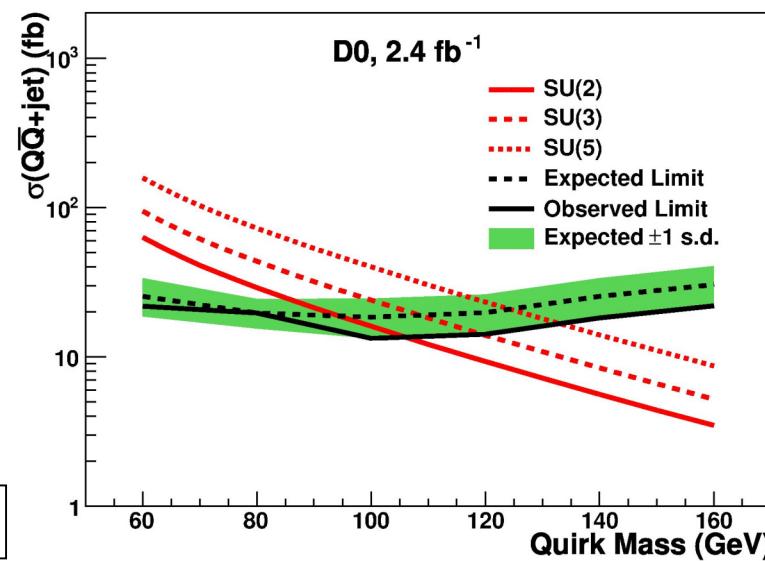


- Investigate $10 \text{ keV} < \Lambda < 1 \text{ MeV}/c^2$ (mesoscopic range) and $60 < M_Q < 160 \text{ GeV}/c^2$
- $L = 2.4 \text{ fb}^{-1}$
- Look for slow, high-ionizing track
- Select an isolated track $> 40 \text{ GeV}/c$, a jet $> 75 \text{ GeV}$ and MET $> 50 \text{ GeV}$
- MET aligned with the track, jet opposite direction
- Main background: W+jets and multijets
- Discriminating variable: dE/dx , measured with the tracking system
- Analysis excludes quirks up to 107-133 GeV depending on the model

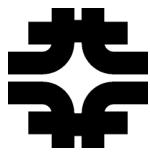
Phys. Rev. Lett. **105**, 211803 (2010)



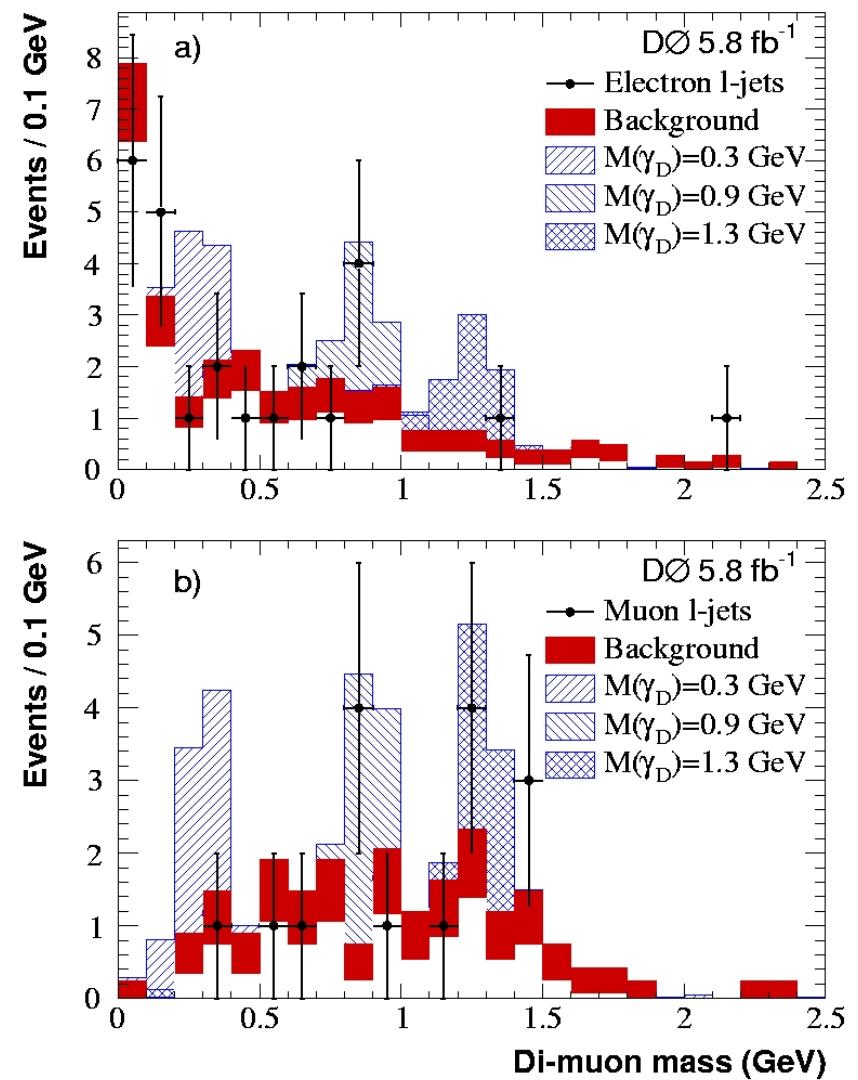
dE/dX



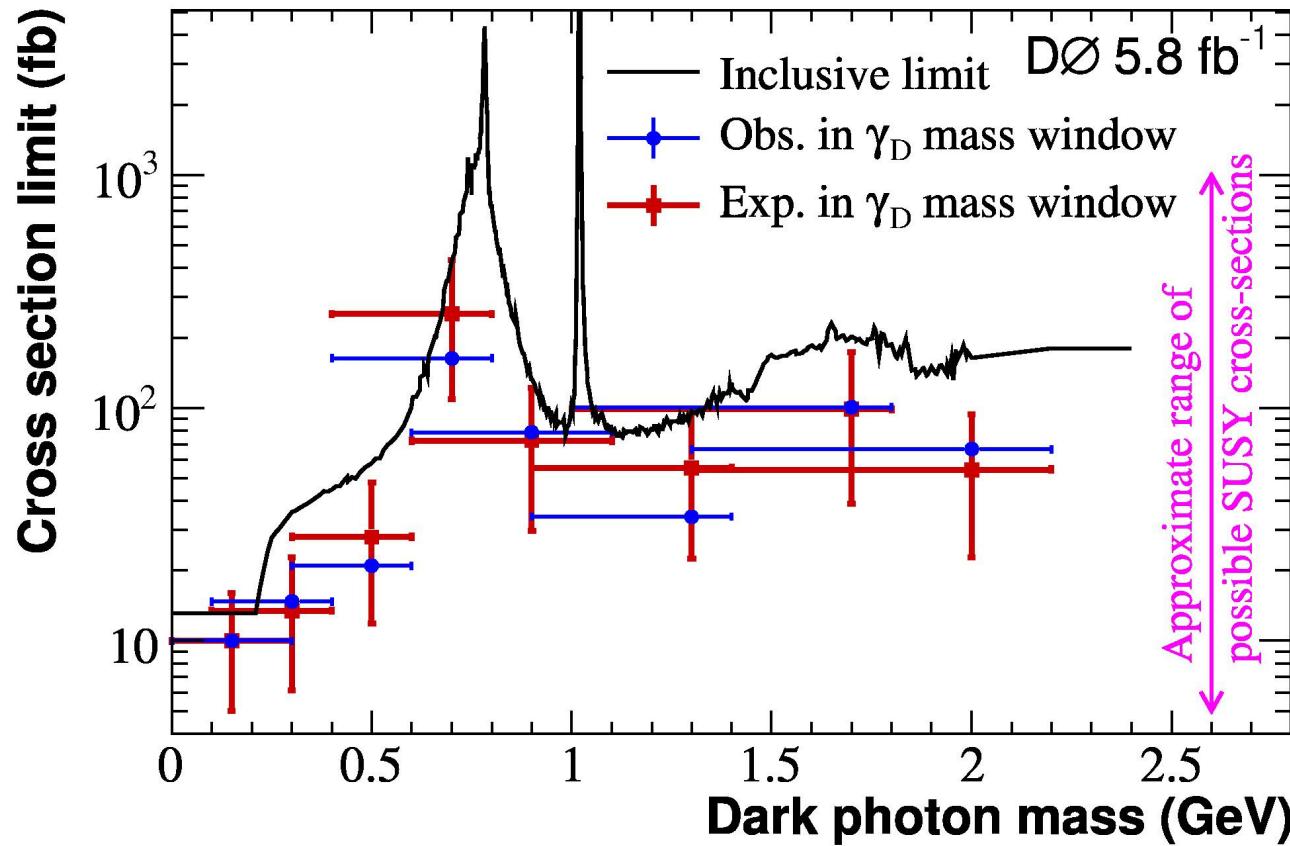
Search for hidden valleys



- Hidden sector's force carrier (dark photon γ_D) will decay to leptons
- Signal is many “lepton jets”
- $L = 5.8 \text{ fb}^{-1}$
- Select a seed electron or muon track $>10 \text{ GeV}/c$ with a companion track of opposite charge of $>5 \text{ GeV}/c$
- $\text{MET} > 30 \text{ GeV}$
- Both track and calorimeter isolation
- At least 2 such “lepton jets”
- Main background: multijet events and (for “electron jets”) conversions
- Results for ee, e μ , $\mu\mu$ and combined
- Form invariant mass of dark photon from seed and companion track



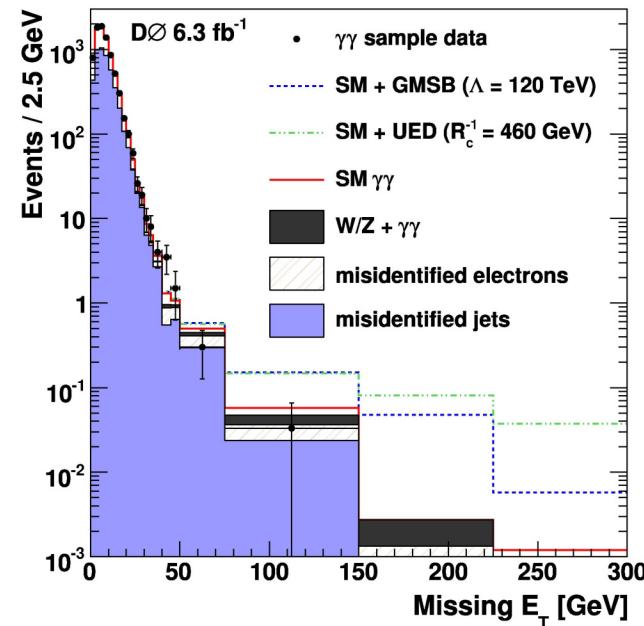
- Limit on the cross-section vs dark-photon mass is set



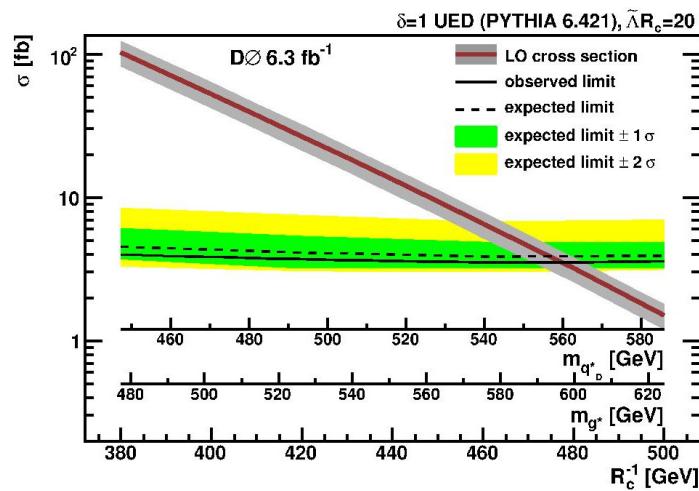
Phys. Rev. Lett. 105, 211802 (2010)

- From the pair production of KK particles we expect 2 photons + MET
- $L = 6.3 \text{ fb}^{-1}$
- 2 photons $> 25 \text{ GeV}$, MET $> 50 \text{ GeV}$
- $\Delta\Phi$ separation between MET and γ or jets
- Background:
 - Fake MET: SM diphotons, γ +jets (estimate using dielectron/diphoton MET shape, fitted at MET<10,20 GeV)
 - Real MET: W+ γ , W+jet, W/Z+ γ
- Observation consistent with SM
- $R_c^{-1} > 477 \text{ GeV}/c^2$ at 95% CL

Phys. Rev. Lett. **105**, 221802 (2010)



MET



- 4th generation is not excluded by electroweak precision measurements and could explain some forward-backward asymmetry in b-decays

- **Search for $b' \rightarrow Wt \rightarrow WWb$**
pair production
- $L = 4.8 \text{ fb}^{-1}$
- $1 e/\mu > 20 \text{ GeV}, \text{MET}>20 \text{ GeV},$
 $\geq 5 \text{ jets} > 20 \text{ GeV} (\geq 1 \text{ b tagged})$
- **Main background:** top pairs
- Main systematics from Jet-energy scale
- Analysis performed separately for $N_{\text{jet}}=5,6, \geq 7$



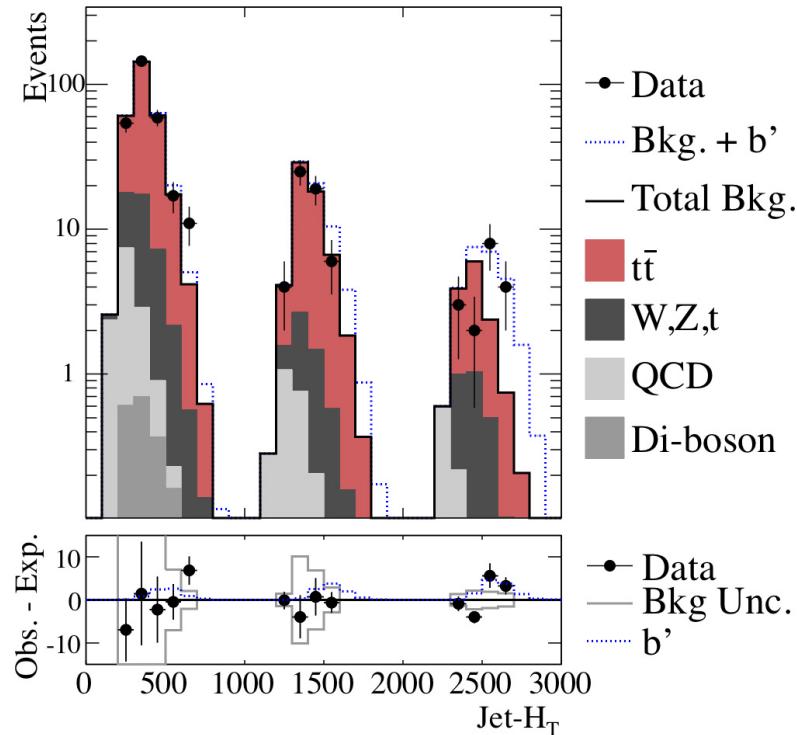
- **Search for $t' \rightarrow Wq$ (not b')**
pair production
- $L = 4.6 \text{ fb}^{-1}$
- $1 e/\mu > 25 \text{ GeV}, \text{MET}>20 \text{ GeV},$
 $\geq 4 \text{ jets} > 20 \text{ GeV}$ (no b-tagging)
- **Main background:** $W+\text{jets}$, top pairs
- Fit the M_{reco} vs H_T distribution
- Main systematics from jet-energy scale
- Data consistent with SM



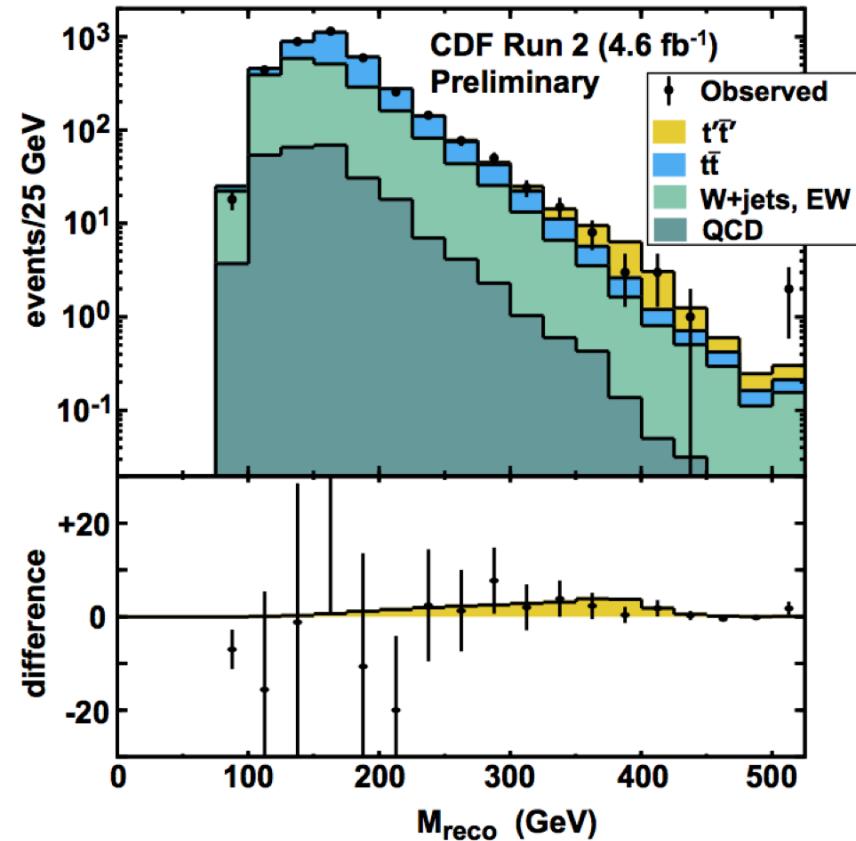
- 4th generation is not excluded by electroweak precision measurements

b' search

CDF Run II Preliminary, 4.8 fb^{-1}

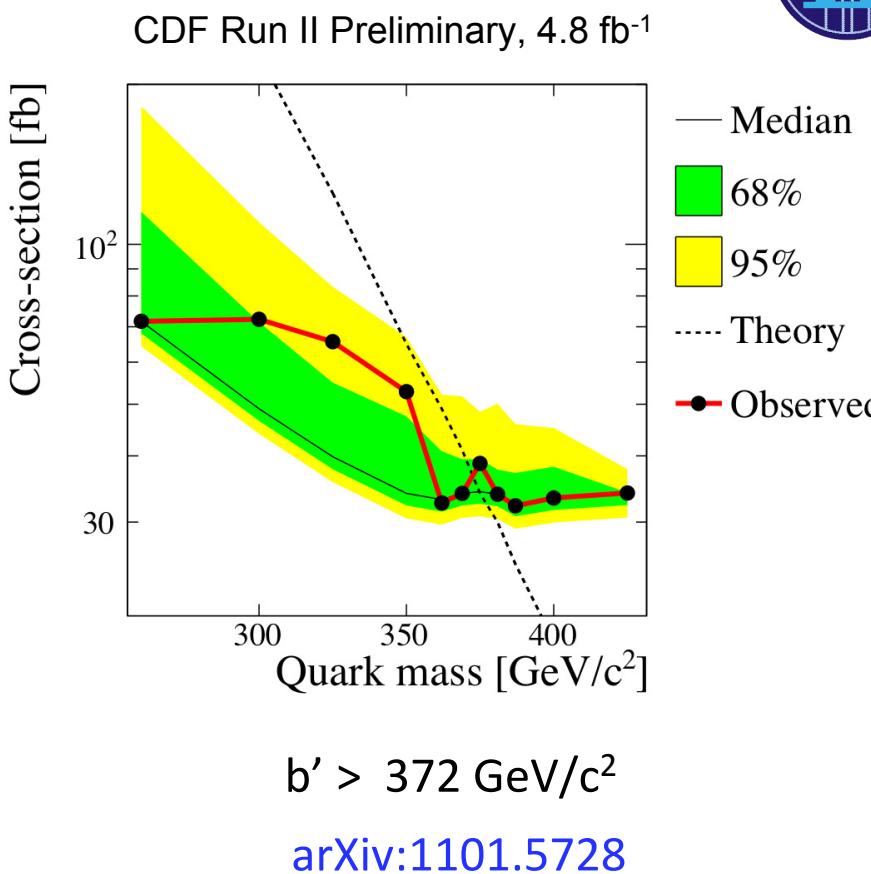


t' search

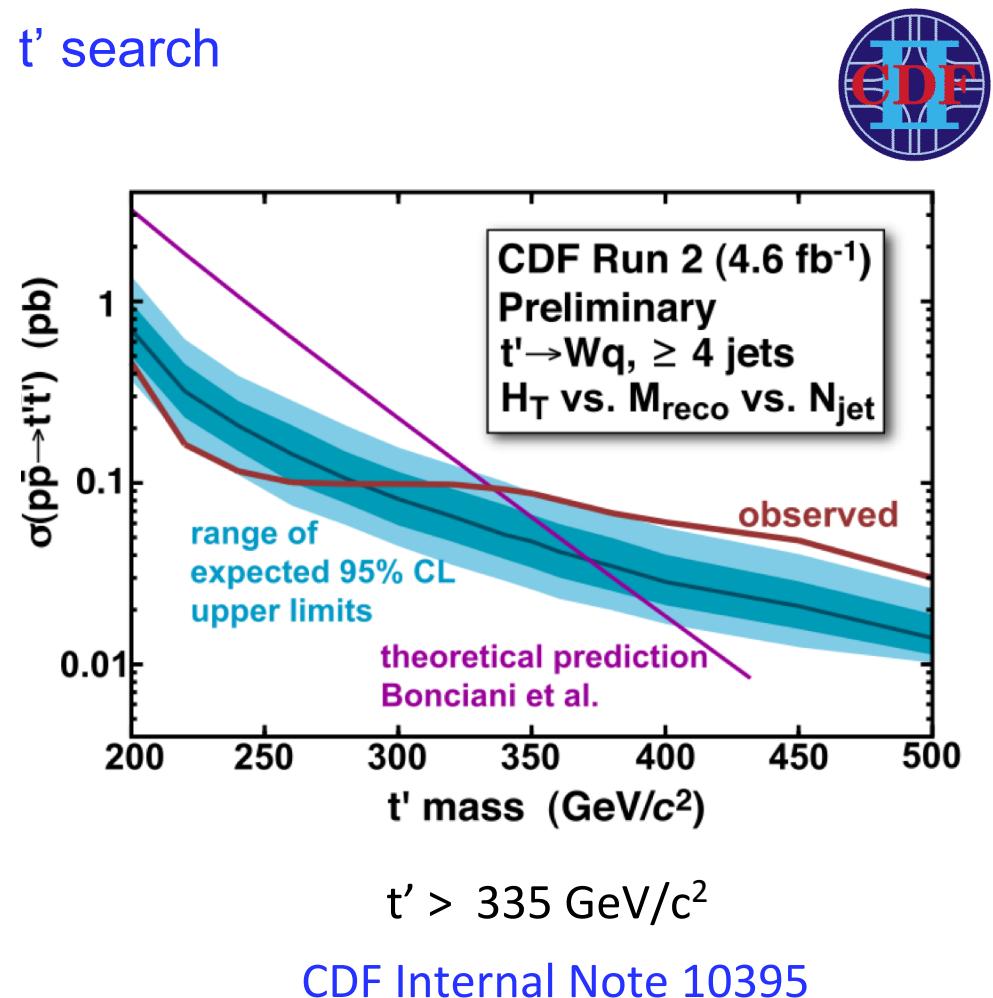


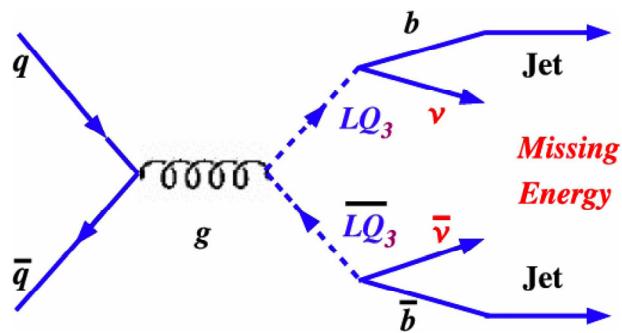
- 4th generation is not excluded by electroweak precision measurements

b' search



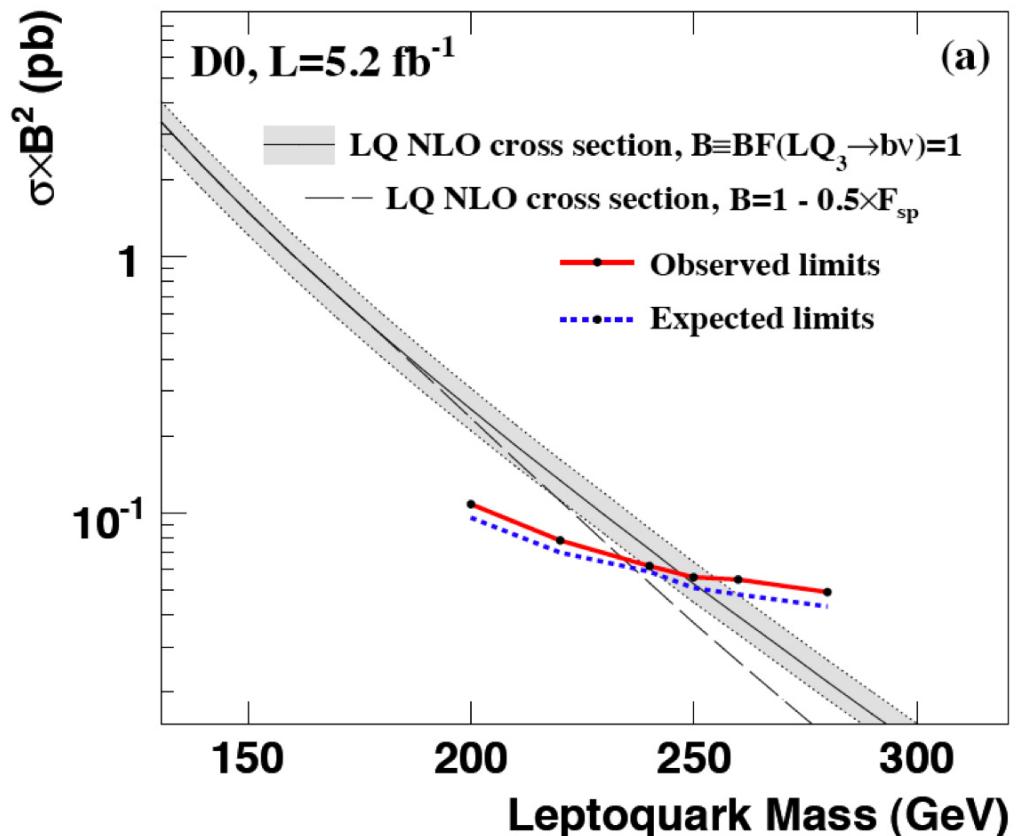
t' search





- $L = 5.2 \text{ fb}^{-1}$
- 2 or 3 jets, $E_T > 20 \text{ GeV}$, at least 2 b-tagged (NN), leptons vetoed
- $\text{MET} > 40 \text{ GeV}$, MET away from jets
- $E_T^{\text{jet}1} > 20, 50 \text{ GeV}$, $\text{MET} > 40, 850 \text{ GeV}$
 $H_T > 60, 220$
 - cuts optimized per mSUGRA point, based on $\Delta M(\text{sbottom-LSP}) = 240$ and $45 \text{ GeV}/c^2$
- **Main backgrounds:** W/Z+jets, multi-jet with fake MET

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$M_{LQ3} > 247 \text{ GeV}/c^2$ at 95% CL